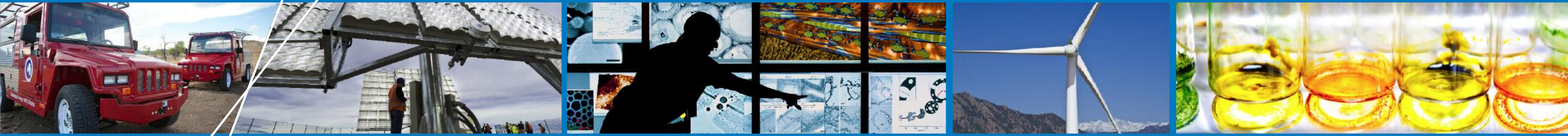
Testing Distributed PV as Part of a Larger Electric System



Presenter: Anderson Hoke, P.E. - NREL

Integrating PV in Distribution Grids: Solutions and Technologies Workshop

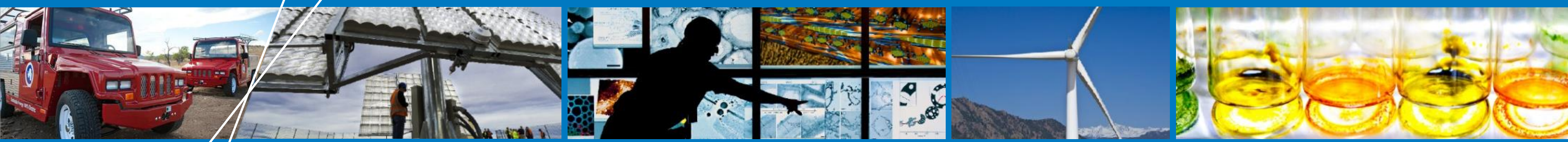
October 23, 2015

Device-level Testing vs. System-level Testing

- Device-level testing
  - Evaluate DER response to external inputs (voltage, frequency, communications, HMI, time)
  - No attempt to characterize effect of DER on larger system
  - E.g. interconnection conformance testing, TrOV testing, efficiency characterization, open-loop advanced grid support function testing
- System-level testing
  - Evaluate DER as part of a system (e.g. distribution feeder, EPS, microgrid)
  - Characterize response of DER to system, response of system to DER, and dynamic interactions between the two
  - System may include many DERs
  - Tests may look at DER-DER interactions
  - May focus on system-level stability, controls, optimization, communications, interoperability, cybersecurity, …

System-level Testing: Two Categories

- Hardware-only
  - Lab testing of multiple integrated hardware articles (e.g. microgrids)
  - Demonstrations of one or more DERs in the field
- Power hardware-in-the-loop (PHIL)
  - Hybrid of simulation and hardware test
  - Part of system tested in hardware, and part simulated in real-time software model
  - Test device(s) in environment that emulates real-world dynamics
  - Useful when:
    - Real system cannot be easily experimented with (e.g. the grid)
    - High-fidelity model of hardware not available
  - Hardware DERs can be scaled to represent larger DERs
  - Hardware elements may or may not be co-located (remote HIL)

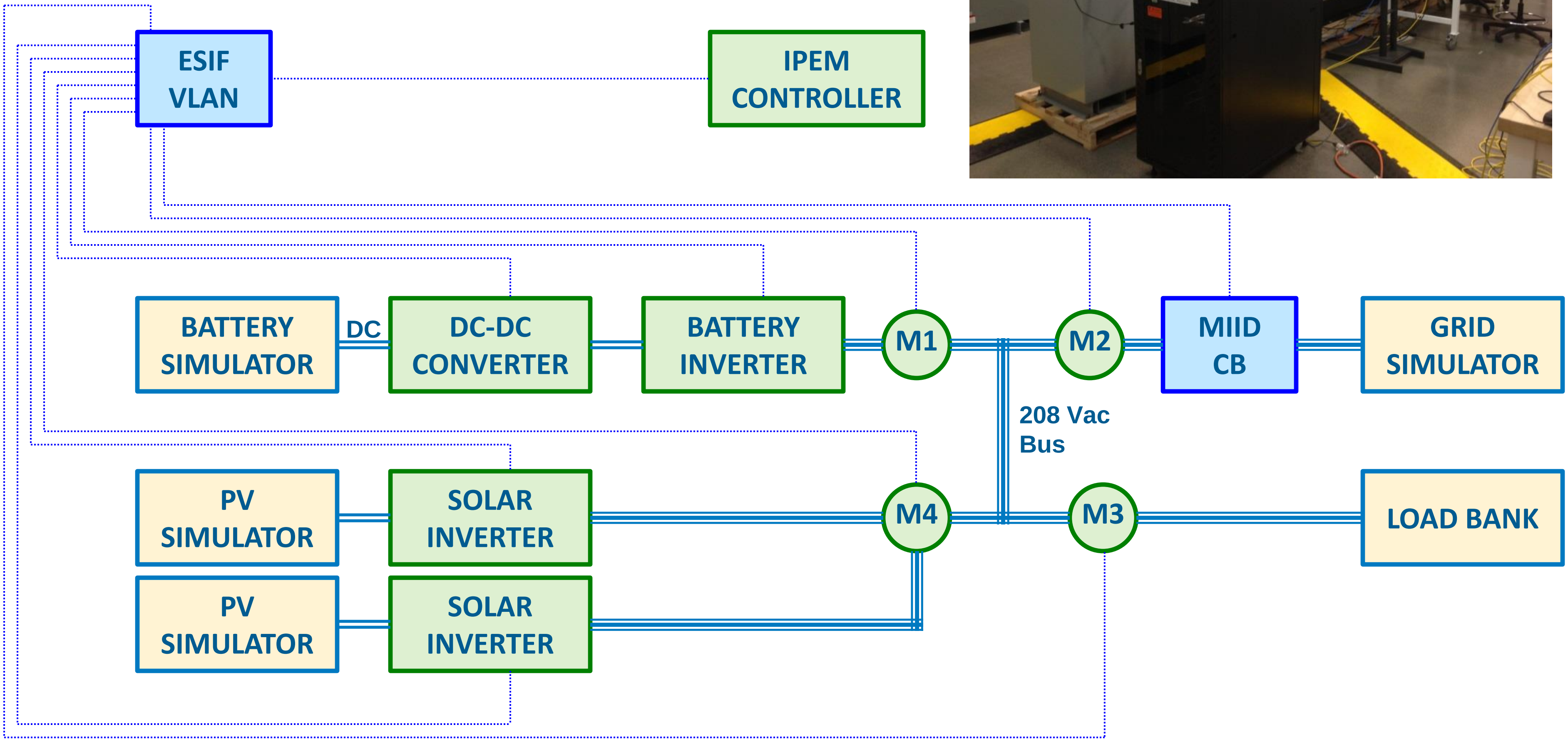


Hardware System Level Testing Examples

Basic Microgrid Controller Testing

Example: Raytheon, CSIRO

- Third-party validation of microgrid controller and other components



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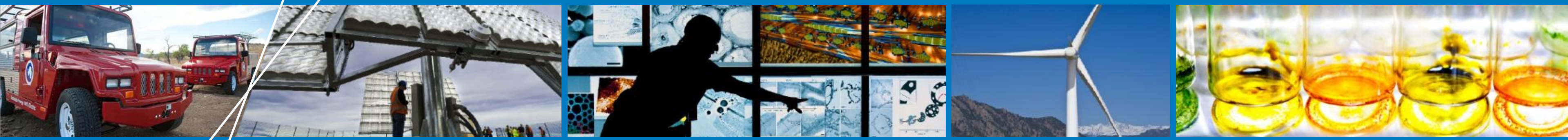
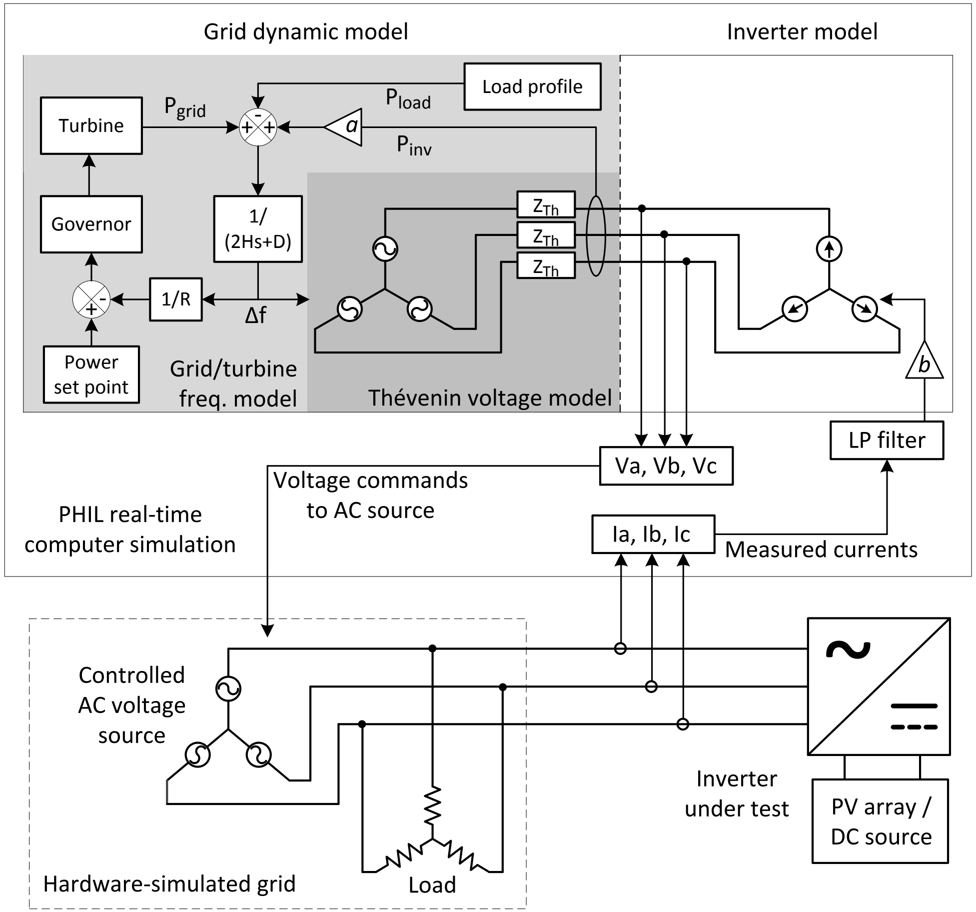


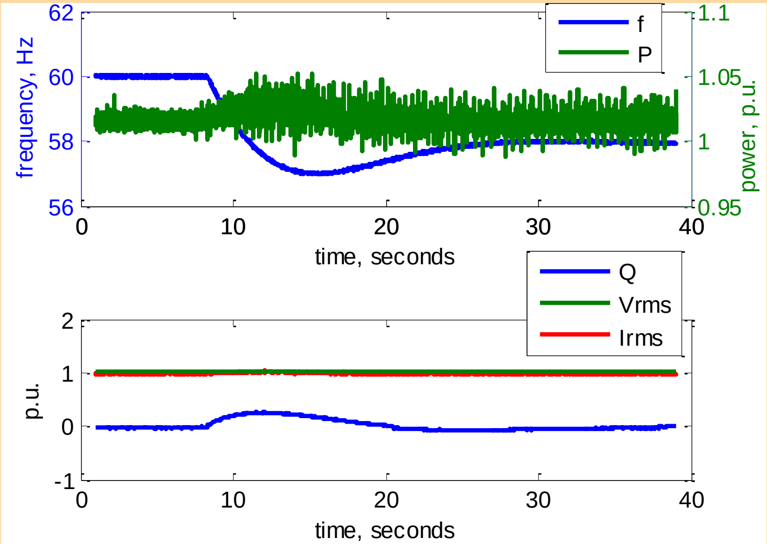
PHIL System-level Testing Examples

PHIL Testing of DER Grid Support Functions

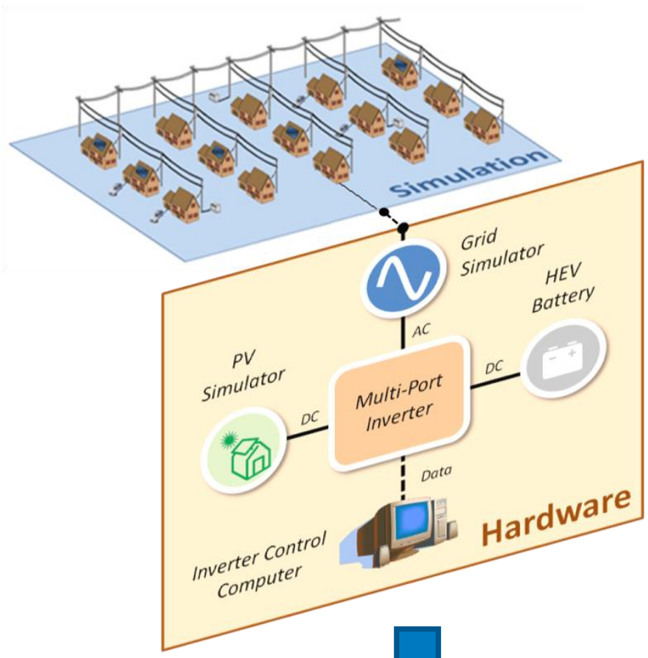


- Hardware testing of advanced inverter/DER features with grid voltage and frequency dynamics simulated using PHIL
- Can simulate multiple PCCs simultaneously

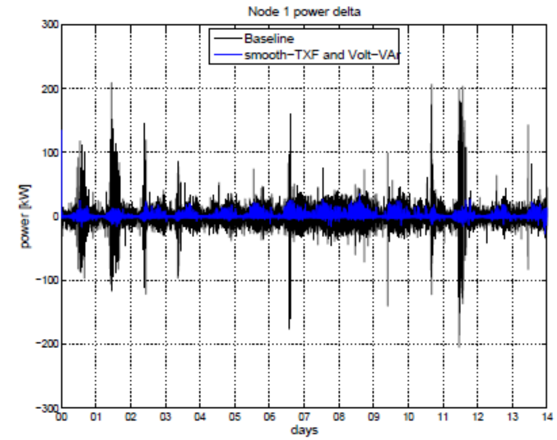
PHIL test emulating major grid frequency event, with commercial advanced inverter performing frequency ride-through:



Distributed PV with Energy Storage



- **Simulation of high penetration of rooftop PV with battery storage on**
  - IEEE123 feeder in GridLAB-D
  - Historical residential commercial load profiles
  - Added control strategies to inverter model:
    - Local Volt-VAR, Inverter smoothing, Transformer smoothing, PV firming, PV curtailment

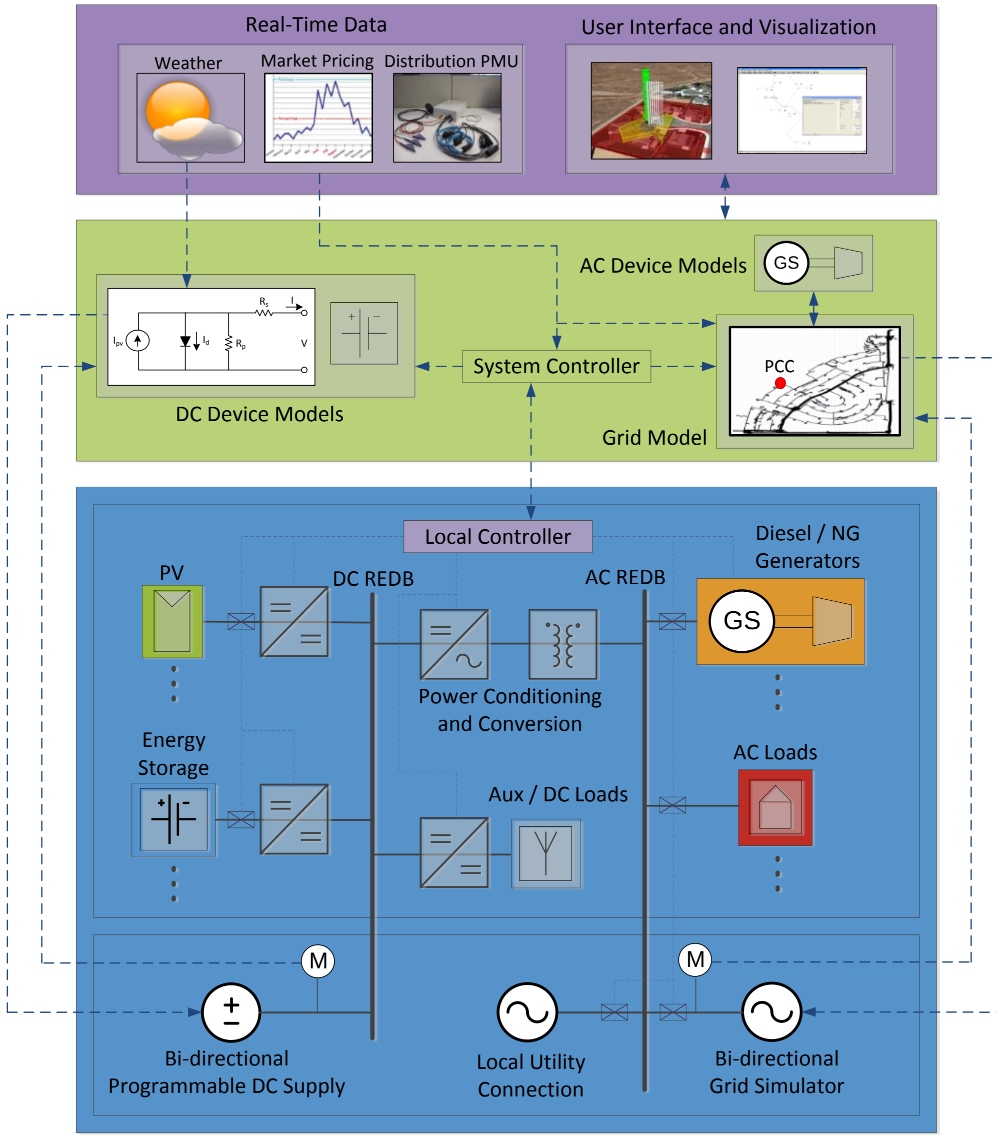


- **PHIL testing at ~10kW scale**
  - Replaced one inverter / PV / battery system in the simulation with hardware

System-level Evaluation of Microgrid Controller

Example: SDGE-Borrego Springs, EPRI

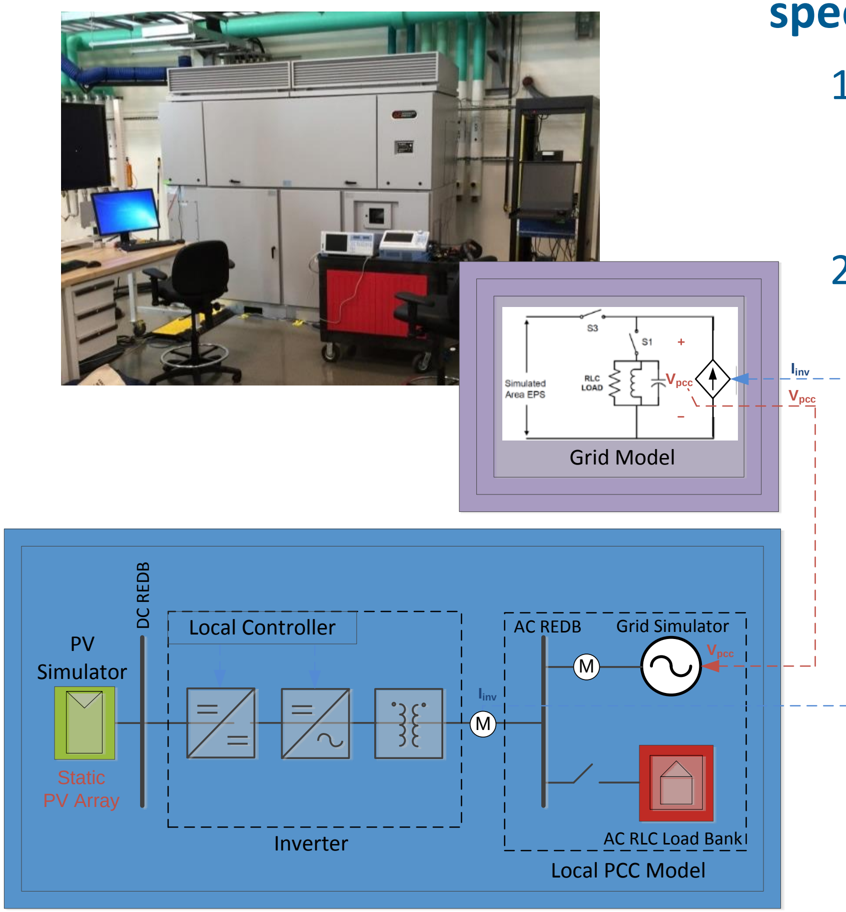
- Evaluation of microgrid controller using hardware at-scale with simulated power systems via power hardware-in-the-loop (PHIL) or controller hardware-in-the-loop (CHIL)
- MW-scale PHIL
- RTDS and Opal-RT

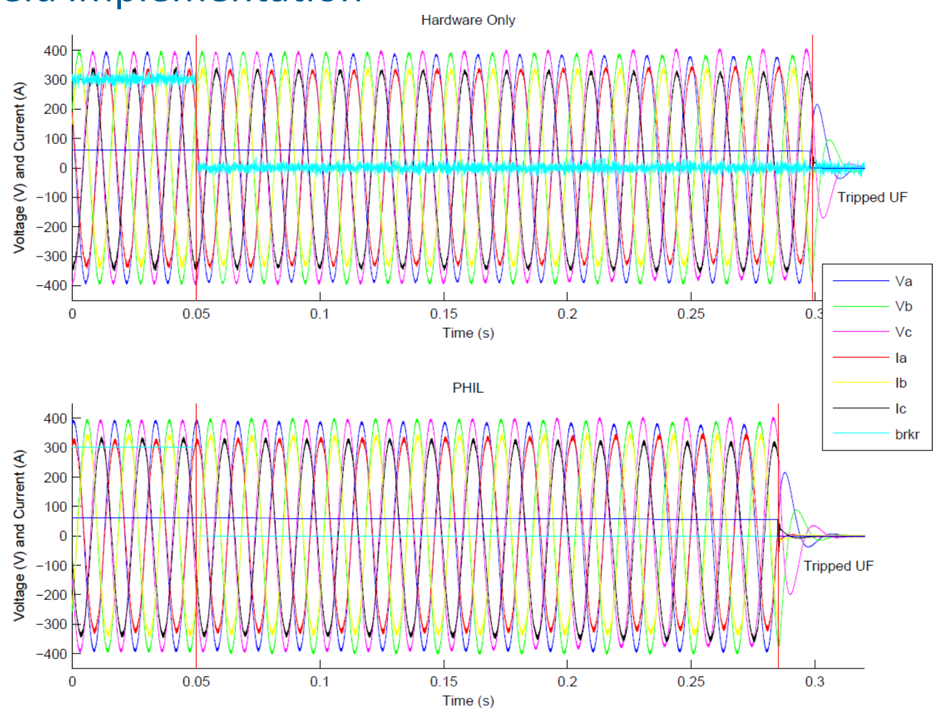


PHIL-based Development and Validation for ESI

Use of PHIL techniques to evaluate novel energy system devices and control systems connected to specific network configurations involves:

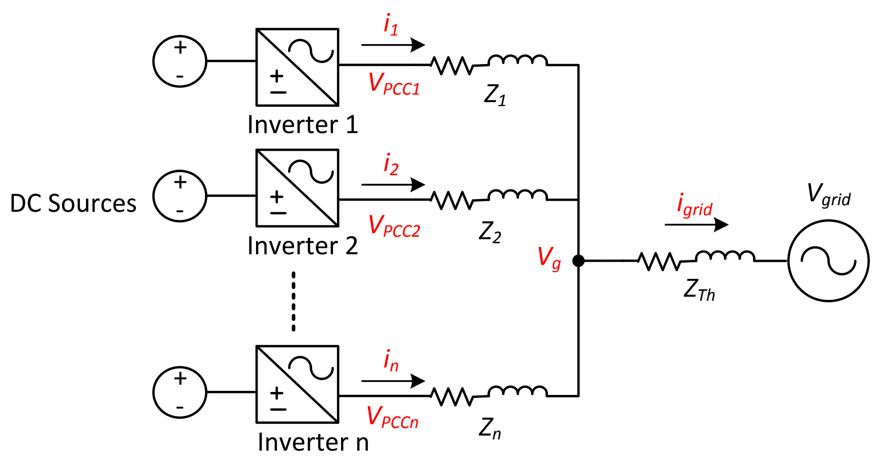
1. Validation of PHIL simulation configuration for a known condition (e.g., field data or hardware) to ensure reliability of technique with particular hardware
2. PHIL simulation with updated devices, models, or control systems to prove new developments before field implementation



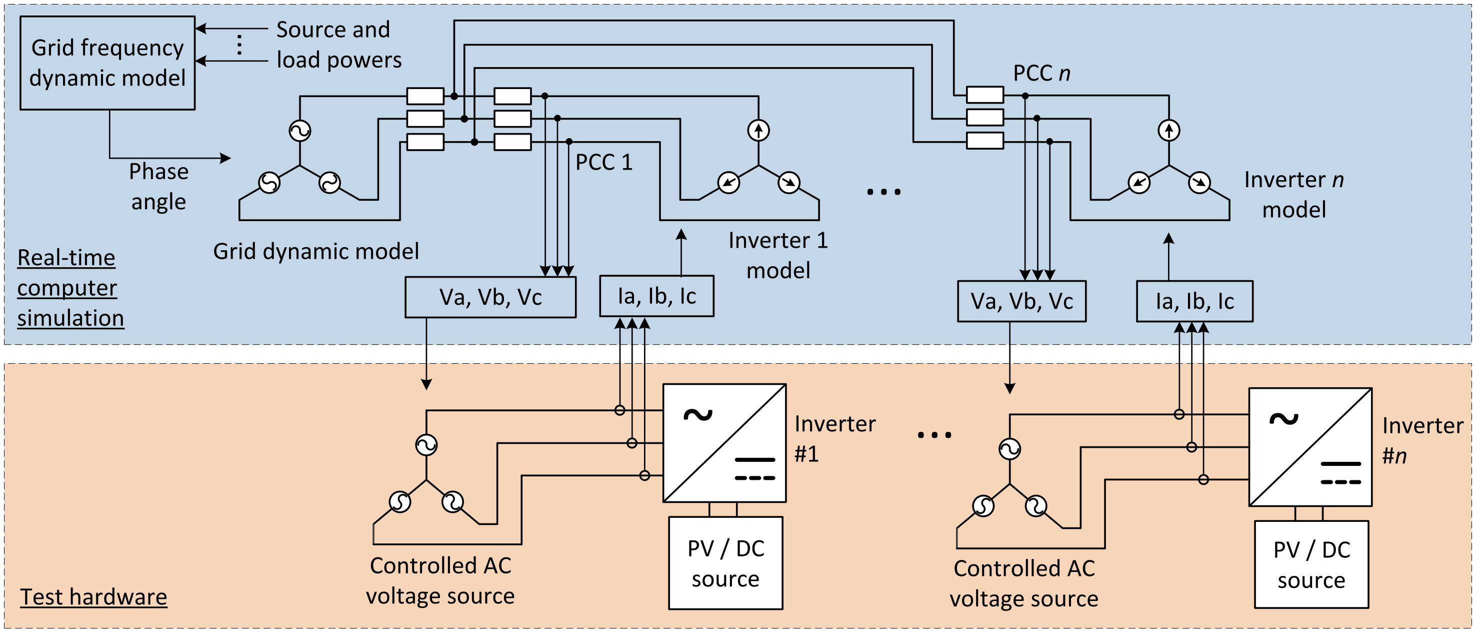


Multiple-PCC PHIL

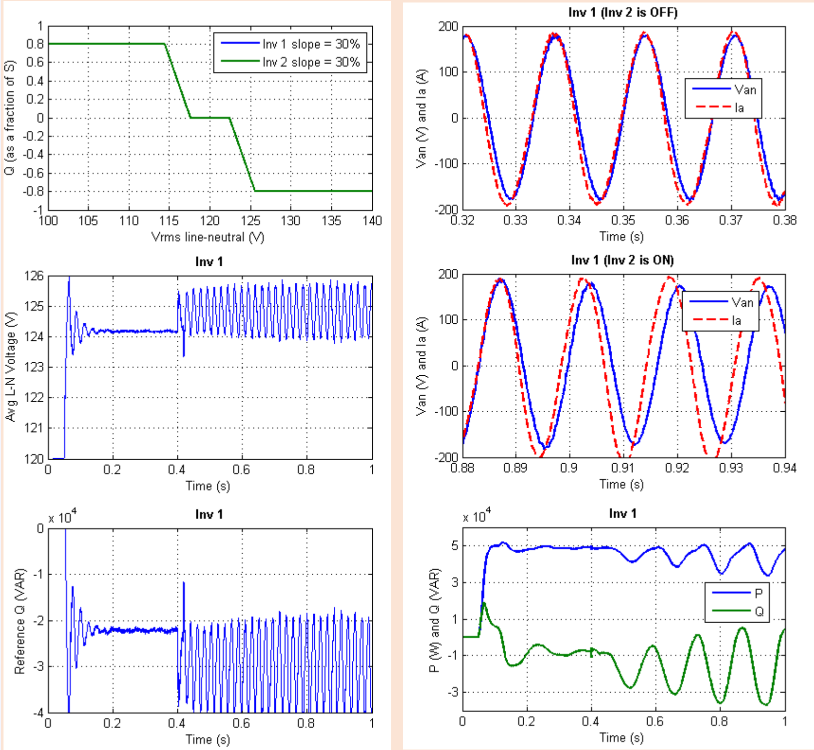
System to be tested:



One possible PHIL test setup:

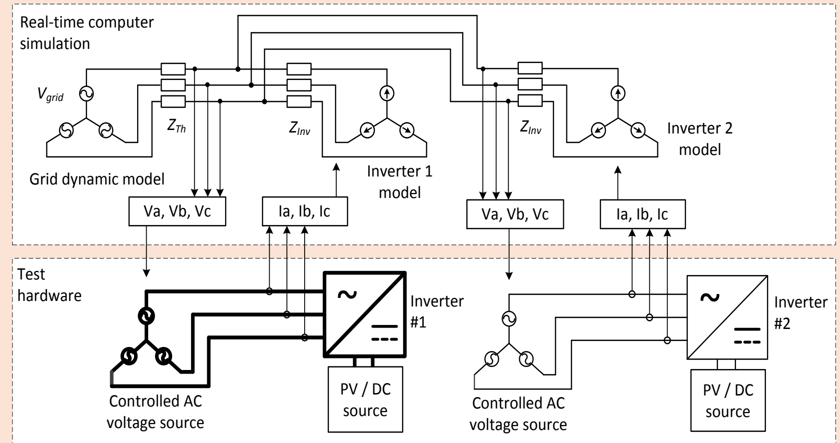


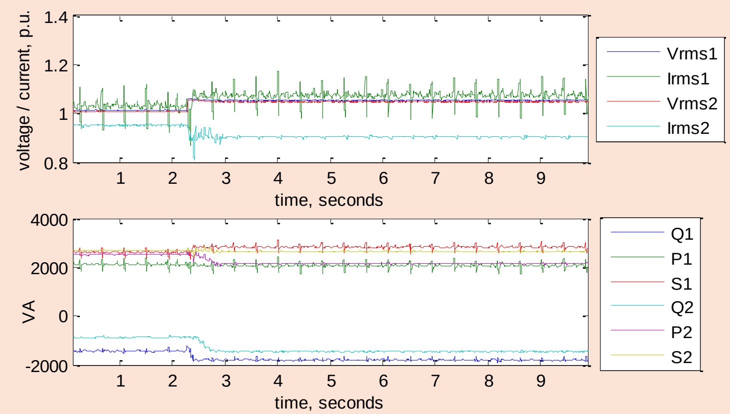
Multi-inverter, Multi-PCC Volt-VAr Test



Reactive power cycling between two inverters with high Q(V) slope

Instability caused by slower volt-VAr response time





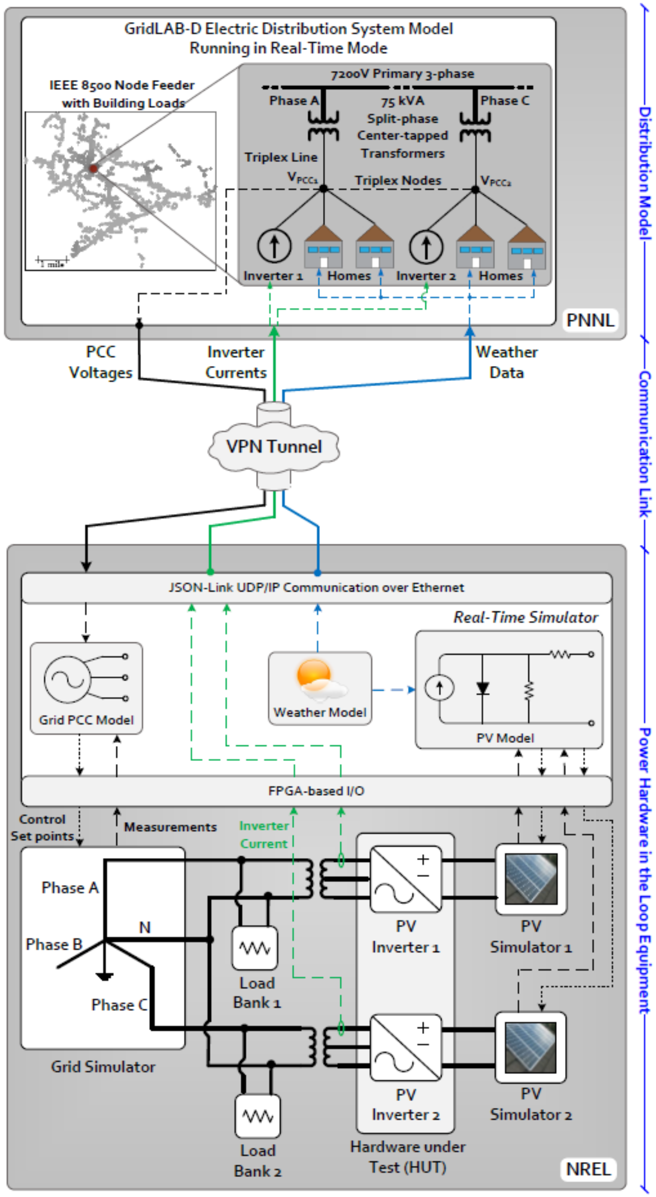
- Simulated impedance in loop with actual inverters – two different inverters from leading manufacturers
- Experimental validation with transient PHIL – no problems found in limited testing to date

Remote PHIL and Co-simulation Test Bed

Combines actual hardware testing using PHIL with co-simulation of larger electric power grid using off-the-shelf modeling tools. Very flexible architecture enables multi-site testing (e.g. NREL links to PNNL and CSIRO), and scenario flexibility

Very Flexible:

- **Arbitrary Grid:** location, topology & equipment
  - Demo: IEEE 8500 and 123 with no hardware changes
- **Any scenario:** normal ops, faults, contingencies
  - Demo: Cloud transients, home thermal physics models
- **Actual hardware:** no proprietary models required
  - Demo: 2 advanced inverters at various points of common coupling
- **Multi-site:** hardware and/or simulation
  - Demo: PNNL (WA) link to NREL (CO)
  - CSIRO (Australia)



Cyber-Physical Microgrid Test Platform

- **NSIL**
  - OMNET++ for network simulation – open source
  - OPNET can be another option, but is costly
- **Hardware**
  - AC grid simulator, load banks, DC power supplies, PV simulators, inverters
  - Equipment under test
- **PHIL**
  - Opal-RT as real-time simulation platform
  - Emulation of energy storage, and distribution feeder